Nationwide Differential Global Positioning System (NDGPS)

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Transportation Policy

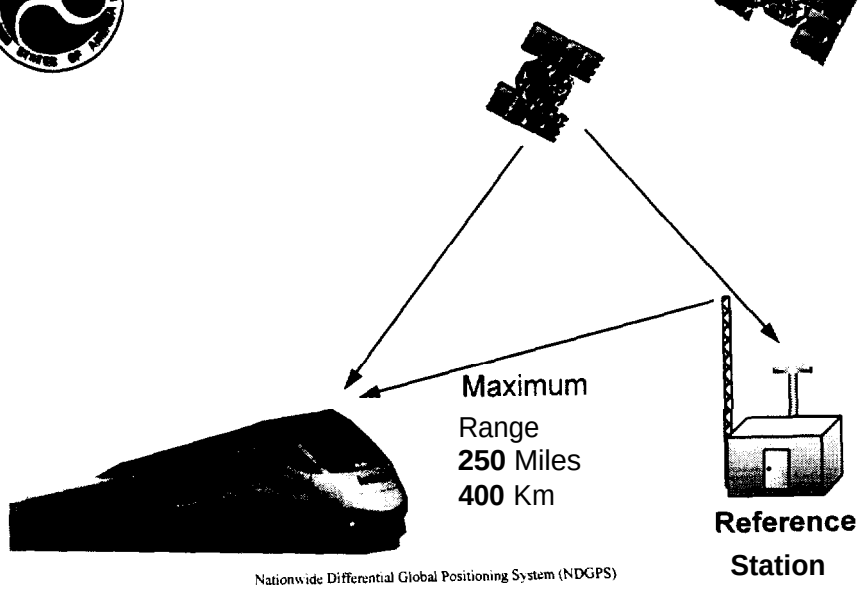
Office of the Secretary of Transportation

Presented to

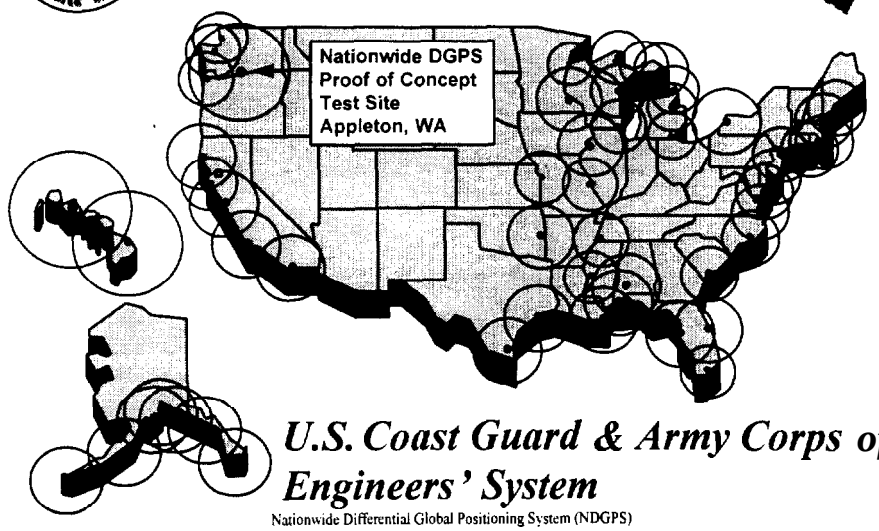
Civil GPS Service Interface Committee

April 7, 1998

DGPS Reference Station



Current DGPS Coverage



U.S. Coast Guard & Army Corps of Engineers' System

Nationwide Differential Global Positioning System (NDGPS)

Need for a Nationwide System

- **Federal, State and Local Agencies**
  - **Began setting up non-standard systems**
- **GAO Study *Global Positioning Technology***
  - **Greater Cooperation Among Federal Agencies**
- ***Technical Report to the Secretary of Transportation on National Approach to Augmented GPS Services***
  - **DOT should plan, install, operate and maintain a nationwide system modeled after the Coast Guard DGPS**

Presidential Decision Directive (PDD)

March 28, 1996

DOT will:

- **"Serve as the lead agency...for all Federal civil GPS matters."**
- **"Develop and implement U.S. Government augmentations... for transportation applications"**
- **Promote "Commercial applications of GPS technologies and the acceptance of GPS and U.S. Government augmentations as standards in domestic and international transportation systems."**
- **Coordinate U.S. Government-provided GPS civil augmentation systems to minimize cost and duplication of effort.**

DGPS Policy and Implementation Plan

- **Plan Development Began in Jan 97**
  - **Executive Steering Group - Joe Canny chair**
  - **Policy & Implementation Team - Len Allen chair**

Participants

DOT/OST	**Department of Commerce**
U.S. Coast Guard	**Department of Interior**
Federal Highways Administration	**Department of Agriculture**
Federal Railroad Administration	**Army Corps of Engineers**
Federal Aviation Administration	**U.S. Air Force**
Environmental Protection Agency	**Various States**

DGPS Requirements
Positive Train Control

- **DGPS use in the Positive Train Control system will:**
  - **Prevent accidents, saving over $60 million per year**
  - **Reduce fuel consumption by better pacing trains**
  - **Increase rail line capacity through closer train spacing, reducing the need for additional capital investment in plant and equipment**

Nationwide Differential Global Positioning System (NDGPS)

Nationwide DGPS
Intelligent Transportation System

- **An integrated vehicle safety system consisting of DGPS, map matching & communication links will:**
  - **Automatically notify emergency personnel when an air bag is deployed, allowing for faster response to the exact location, thus saving some of the 41,000 people who die on U.S. roads each year.**
  - **Automatically reroute traffic around an accident, preventing multi-car pile-ups & improving traffic flow.**
  - **Plot cost effective trips, thus saving both time and fuel.**

Nationwide Differential Global Positioning System (NDGPS)

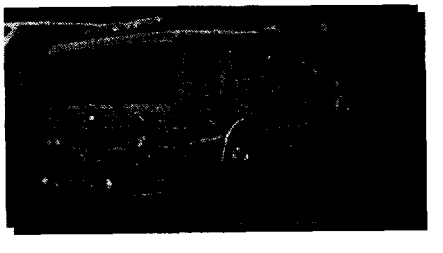
DGPS Requirements
Other Federal Agencies

- 24 Federal Agencies have Public Safety needs
- EPA - Locate 1.4 million hazardous material sites
- DO1 (National Park Service) -
  Search and Rescue, tire fighting and oil spills
- DOE - Continuously monitor shipments of radioactive materials
- DOJ - Locate FBI & DEA personnel in danger & track vehicle location
- DOA - Fire fighting and resource management
- Bureau of Land Management - mapping natural resources and tracking tire fighting equipment
- U.S. Postal Service - tracking over 80,000 postal carriers

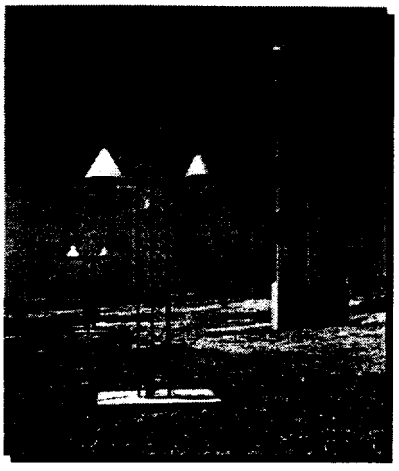
DGPS Requirements
State & Local Governments

◆ **State and Local Governments need DGPS for:**

- Mapping transportation infrastructure
- Police, fire & ambulance emergency 911 response
- Monitoring police officers' safety
- Location of fire hydrants in snow
- Monitoring contaminated well water
- Natural Resource Management



What does NDGPS give me?
System Characteristics



- **Accuracy**
  - **0.5 meter near the reference station**
  - **Add 1 meter/l50 Km**
  - **Accuracy with Post Processing is 5 cm**
- **Integrity**
  - **5 seconds at 100 bps**
  - **2.5 seconds at 200 bps**

Nationwide DGPS
System Characteristics

- **Redundant Coverage Nationwide**
- **Availability 99.999%**
- **Continuous integrity monitoring by USCG**
- **Nonproprietary International Standard**
  - **RTCM SC-104 and ITU-R M.823 compliant**
  - **31 countries operate compatible systems**
  - **Resulting in a seamless international system**

Implementation

The GWEN Opportunity

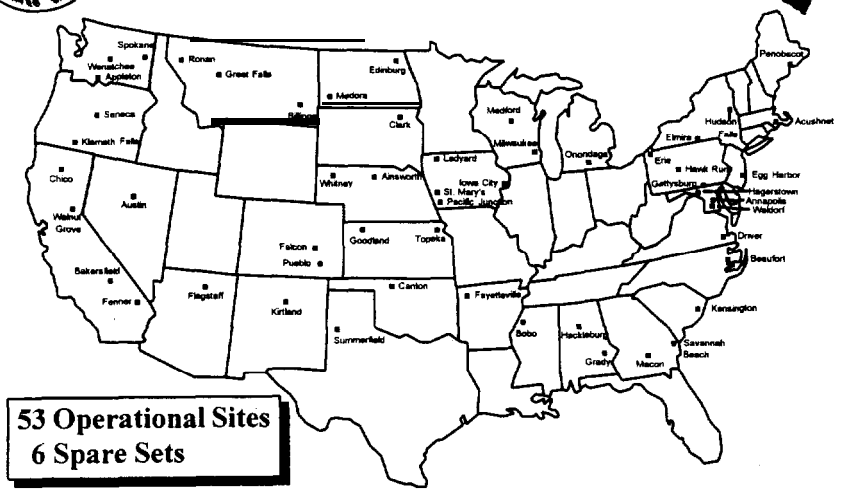
- **Ground Wave Emergency Network (GWEN)**
  - **Air Force plans to decommission the GWEN**
  - **DOT will convert the GWEN sites into DGPS sites**
  - **One of the largest Defense to Civil conversions in history**

Number of Sites	Single Coverage	Double Coverage
GWEN	21	12
Moved or New	22*	11

* Includes 12 sites in Alaska

Nationwide Differential Global Positioning System (NDGPS)

GWEN Sites



53 Operational Sites
6 Spare Sets

Nationwide Differential Global Positioning System (NDGPS)

DOT Appropriations

Early Start in 1998

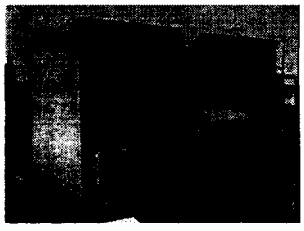
- **Amendment by Senators Daschle & Johnson**
  - **Amendment was consistent with our efforts**
  - **Required a start in FY98 vice FY99**
  - **Signed into Public Law (105-66) on Oct 27, 1997**
  - **The law authorizes NDGPS and provides $2.4 M**
- **The Air Force agreed to release some GWENs early to allow us to begin installations.**
  - **Currently removing 3 sites from the AF network--Chico, CA; Whitney, NE; Savannah, GA**

Converted GWEN to NDGPS

Appleton, WA

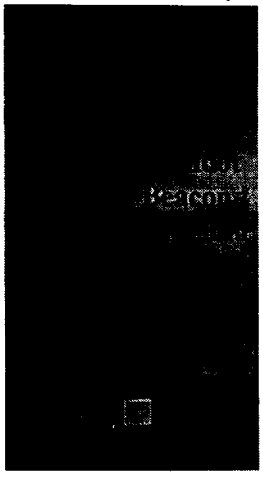
Range
200 to 250 miles
320 to 400 km

Reference & Integrity Antennas
Two sets of each



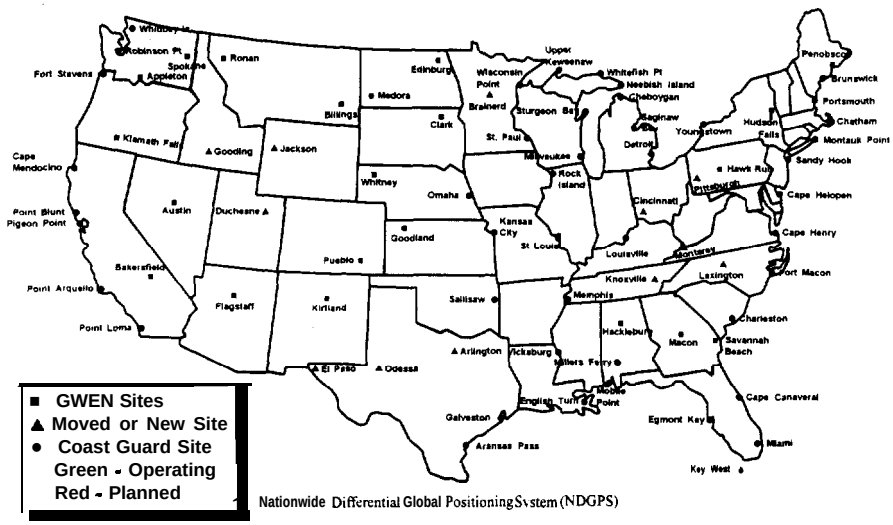
DGPS Equipment Shelter

There is a similar shelter for the 25KW generator



Nationwide DGPS

Phase I - Single Coverage



Nationwide Differential Global Positioning System (NDGPS)

Nationwide DGPS

Phase II - Double Coverage

Nationwide Differential Global Positioning System (NDGPS)

Who will do what?

Teamwork

- Air Force - Transfer GWEN equipment
- ACOE & States - Acquire & Prepare sites
- Coast Guard - Technical Support
  - Installations
  - Command & Control
- FHWA - Document System Performance
- FRA - Project Sponsor (funding & personnel)
- NOAA - Integrated Precipitable Water Vapor
  - Monitor Reference Stations (CORS)
- OST - Program Coordination

Nationwide Differential Global Positioning System (NDGPS)

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Nationwide Differential Global Positioning System

With an unprecedented level of cooperation among Federal and state agencies, the Department of Transportation will expand the Coast Guard's Differential Global Positioning System (DGPS) into a nationwide system. The Nationwide Differential Global Positioning System (NDGPS) will soon blanket the nation with a navigation service that is the most accurate, most reliable and has the highest degree of integrity of any navigation system the country has ever seen. But the system will be more than a navigation system. It will also be **used** in a wide array of other applications such as surveying, weather modeling and precision farming.

You might think that a system like that would cost billions to build, but the proven Coast Guard design will only cost $30 million to implement. Converting Ground Wave Emergency Network (GWEN) sites that the Air Force is decommissioning into DGPS reference stations will save the Department of Defense about $6 million in GWEN decommissioning costs and save the Department of Transportation about $10 million in NDGPS implementation costs. It's a win win situation. And with the recent passage of Public Law 105-66, Section 346, we have both the authority and the funding to immediately begin installations.

Like GPS, NDGPS will benefit government, industry and the general public. In 1977, the Air Force launched its first prototype GPS satellite, which gave birth to a program which would eventually cover the earth with an accurate navigation, timing and positioning system. In 1984, after Korean Airline Flight KAL-007 strayed off coarse and was shot down by the Soviet Union, President Reagan guaranteed civilian access to the GPS signal. Thus, the Air Force designed GPS to be a dual use system to meet the needs of both the military and civil sectors. As a result, the GPS signal specification defines two services. The first is the Precise Positioning Service (PPS), which is for the military and select government users and has a horizontal accuracy of 22 meters. The second is the Standard Positioning Service (SPS), which is available to the general public and has a horizontal accuracy of 100 meters.

The utility of a worldwide navigation, positioning and timing system that is free of user fees led to the enormous success and acceptance of GPS. It also created a rapidly growing GPS industry. **But as** successful as GPS is, it still isn't good enough for some applications.

Many applications demanded better accuracy, integrity and availability then either the SPS or even the PPS services provide. The first augmentation system that was developed to address these shortfalls is the Coast Guard's Differential Global Positioning System. The Coast Guard needed a radionavigation system which would provide better than 10 meter navigation accuracy along navigable waterways of the United States to improve the safety of maritime traffic. The Coast Guard also needed the improved accuracy of the system to more efficiently position the thousands of navigation **buoys** which line the rivers and harbors of the United States. The Coast Guard's DGPS uses a system of reference stations to provide range corrections and integrity checks to users up to 250 miles from the reference station. The range of the signal is a function of the transmit power of the reference station, the ground conductivity and the skywave propagation of the signal.

The reference station continually monitors all of the GPS satellites that are in view. Since the reference station is surveyed, its precise location is known. Using this known position, the reference station calculates a correction for each satellite which is in view. The DGPS user receives the GPS signals from the satellites and the DGPS corrections from the reference station. Applying the corrections, to the satellite pseudo ranges, gives the DGPS user an accuracy which is typically **between I-3** meters, depending on the distance the user is from the reference station. The accuracy near the reference station is about a half meter but the accuracy degrades by about 1 meter for every 150 kilometers in distance that the user is from the reference station. The real-time accuracy, from the DGPS reference stations, meets the accuracy requirements of a wide range of applications from maritime navigation to Positive Train Control to land navigation and to precision farming.

In addition to accuracy, integrity is essential to the navigation systems. Unfortunately, with GPS it can take 2 to 4 hours for a GPS satellite, which is operating outside the acceptable parameters, to pass over a control site where it can be flagged as being out of tolerance. DGPS, on the other hand, continuously monitors the satellites and, if a satellite is so far out of tolerance that it can't be corrected, the user is notified within 2.5 to 5 seconds. This time to alarm, integrity is very important in land, sea and air navigation applications, where the safety of lives are at stake.

After some initial research and development in the late 1980's by the Coast Guard's R&D Center, deployment of the Coast Guard DGPS system began. Currently, the Coast Guard's DGPS covers the coast of the United States and navigable waterways of the Mississippi River. The system was designed to be fully compliant with of the RTCM SC-104 and ITU-R M.823, domestic and international standards. However, as the Coast Guard was deploying its standard system, other Federal and state agencies began developing non-standard systems which could not be used by other agencies., In a September 1994 report, the General Accounting Office encouraged greater cooperation among federal agencies in the development of differential systems. This comment was echoed in a December 1994 report entitled, *A Technical Report to the Secretary of Transportation on a National Approach to Augmented GPS Services,* which is more commonly referred to as the Augmentations Study. The Augmentation Study recommended that the Department of Transportation plan, install, operate and maintain a nationwide system modeled after the Coast Guard's DGPS. In March of 1996. the President established the GPS strategic goals and management structure, in Presidential Decision Directive NSTC-6 (PDD). The PDD assigned the responsibilities of leadership over civil GPS matters and the development of GPS augmentation systems for transportation applications to the Department of Transportation.

In January 1997, the Department formed an interagency NDGPS Executive Steering Group and NDGPS Policy and Implementation Team to lead the implementation of the nationwide system. The NDGPS Policy and Implementation Team revalidated the findings of the Augmentation Study, documented the requirements of many Federal and state agencies, evaluated alternative methods of providing differential corrections, documented benefits, and developed a cost benefit analysis in accordance with OMB circular A-94. This work is documented in the team's *Nationwide DGPS Report.* Many public safety applications are identified in the report, including saving lives on the railroads and highways.

The use of NDGPS in the Positive Train Control system will: (1) prevent accidents saving over $35 million per year, (2) reduce fuel consumption by better pacing trains, and (3) increase rail line capacity through closer train spacing, thus reducing the need for the construction of new rail lines.

Someday GPS/NDGPS receivers will be as common in cars as AM/FM radios are today. An integrated vehicle safety system consisting of a NDGPS receiver, collision sensors and communications links can help prevent accidents and notify emergency personnel when an accident does occur. A collision sensor, similar to the sensor in an air bag, could automatically send a preformatted message over a cell phone to an emergency response center at the instant an accident occurs. The message would contain the exact location of the accident from the NDGPS position. No longer will an injured person have to wait for a good Samaritan to drive by the accident. locate a phone and call for help. The notification will be instantaneous. The emergency response team could use the NDGPS receiver to automatically plot the fastest route to the accident, taking into account the roads which are blocked by traffic. Thus, the notification time will be completely eliminated and the emergency response team's time will be greatly reduced. It is estimated that this could save up to three percent of the 41,000 people who die on U.S. highways each year, which amounts to 1,230 lives.

Similarly, a communications link from the emergency response center to cars equipped with NDGPS receivers could indicate where accidents have occurred. The NDGPS receiver could plot accident locations on an Electronic Graphic Display Unit and provide an audible warning to the driver as he approaches the accident. This warning of an accident a mile or two ahead could prevent multi-car pileups in poor visibility or icy conditions.

Many other Federal and state public safety requirements were identified by the NDGPS Policy and Implementation Team. For example, NDGPS could be used in search and rescue, fire fighting, oil spill response, monitoring shipment of hazardous material, and mapping contaminated water supplies. In fact, many of these functions are currently being performed using DGPS in areas covered by the Coast Guard's system.

Since our plan is to reuse the Air Force's GWEN sites, as they are decommissioned, we asked the Air Force if we could remove one site from the network to convert it into an NDGPS site as a proof of concept. They agreed and we converted the GWEN site in Appleton, WA last May. This first NDGPS site has been transmitting flawlessly since then. Moreover, the efficiency of the 300 foot, reused GWEN antenna far exceeded our expectations. While a typical Coast Guard DGPS antenna is between 1.5 and 23 percent efficient, we anticipated that the larger GWEN antenna would have an efficiency of about 35 percent. But the near perfect match between the

antenna and the NDGPS frequency resulted in an exceptional 51 percent efficiency. This means, that instead of radiating 150 to 230 watts, which is the power we would get from a typical Coast Guard antenna, the converted GWEN antenna pushes out 510 watts. The range of the Appleton site is about what we expected, 200 to 250 miles, depending on the terrain and ground conductivity.

The Appleton site is also being used as a proof of concept for the use of NDGPS in the Positive Train Control system. We ran tests on trains along both sides of the Columbia River Gorge and the NDGPS signal was received the entire length of the gorge.

In July 1997, Senators Daschle and Johnson from South Dakota attached an amendment to the Department of Transportation's fiscal year 1998 appropriation bill, which authorizes the NDGPS program and provides first year funding. The amendment was incorporated into Section 346 of the final bill. Despite some initial opposition from the Office of Management and Budget (OMB), the bill was signed into law by the President on October 27, 1997, as Public Law 105-66. Section 346 of the law outlines the requirements and establishes the authority for NDGPS. A copy of section 346 is attached. The law also provides $2.4 million, in fiscal year 1998, to begin the installation of the system.

So what will the NDGPS service give us? In addition to the accuracy of 1 to 3 meters and the integrity, time to alarm of 2.5 to 5 seconds, the NDGPS will provide dual coverage nationwide. That means, anywhere in the country, you will be able to receive corrections from at least two reference stations. Thus, if an unusual occurrence eliminates the signal from one reference station, such as a lightening strike at one of the reference station or radio interference that jams one reference station, the other reference station will ensure continuous service. The percent of time that a service is available is referred to as operational availability. Since a single reference station is design to provides an operational availability of 99.7 percent, dual coverage will provide an availability of 99.999 percent as illustrated below:

$$A_o = (RS1_{Ao} + RS2_{Ao}) - (RS1_{Ao} \times RS2_{Ao})$$

$$A_o = (99.7 + 99.7) - (99.7 \times 99.7)$$

Where: A_o is the Operational Availability

$RS1_{Ao}$ is the availability of the first reference station

$RS2_{Ao}$ is the availability of the second reference station

NDGPS receivers could also be designed to use the information from two or more reference stations to develop a more accurate position than a single reference station can provide. This technique is referred to as the Regional Area Augmentation.

The NDGPS system will be installed using commercial products and services and will be maintained through commercial services contracts. Thus, the NDGPS program will maximizes the use of commercial products and services, which is required by both the PDD and Public Law 105-66 section 346.

As mentioned earlier, the NDGPS will reuse Ground Wave Emergency Network (GWEN) sites which the Air Force no longer needs. The Air Force has 53 operational sites and 6 "complete" (I'll believe it when I see it) spare systems. We will reuse the 300 foot broadcast antenna, two equipment shelters and a 25KW generator at each site. Since our NDGPS coverage model predictions that we will need 66 sites, we will have to purchase some additional antennas, equipment shelters and generators.

Unfortunately not all of the GWEN sites are where we need them. Thus, we will have to move some of the sites to new locations. The plan calls for 33 GWEN sites in their current locations, 26 moved GWEN sites and 7 new sites. Reusing the GWEN system will save the Air Force about $6 million in GWEN decommissioning costs and the Department of Transportation $10 million in NDGPS installation costs. This will also result in one of the largest defense to civil system conversions in history, benefiting DOD, DOT and the tax paying public.

The sites will be installed in two phases. The first phase will provide single coverage to the entire country. The second phase will provide dual coverage. Based on current budget constraints, the program will take four to five years to complete.

Our use of the NDGPS in the Positive Train Control system and in Intelligent Transportation Systems will promote this U.S. government augmentation system as a standard in transportation systems, as required in the PDD. The format of the broadcast signal will also be fully compliant with both RTCM SC- 104 and ITU-R M.823. These non-proprietary international standards are now used in over 22 other countries, leading to a seamless international system. The broadcast of the NDGPS corrections will be free of

direct user fees as required under Public Law 105-66, Section 346. This will further encouraging acceptance of the standard. An additional benefit of using an open, internationally accepted standard, is that it creates a world market for all United States GPS equipment manufacturers and creates lower equipment costs for users through economies of scale and competition. Thus, both the manufacturers and users benefit.

The NDGPS sites will be integrated into three Federal systems: the Coast Guard's DGPS system for continuous integrity monitoring and control, the National Geodetic Survey's Continuously Operated Reference Station (CORS) system for high accuracy (5 centimeter) positioning applications, and the National Oceanic and Atmospheric Administration's Integrated Precipitable Water Vapor System for real-time input of water vapor data into the national weather models. From a national security perspective, the system will be operated by governmeni, and thus can be denied to enemies of the United States, if the need arises, which is required by Public Law 105-66, Section 346.

The *Nationwide DGPS Report* was developed through the exceptional teamwork of several federal and state agencies and private contractors; the implementation will be done in a similar fashion. A Memorandum of Agreement (MOA) among six federal agencies is currently being developed which delineates the anticipated implementation responsibilities as follows. The Air Force will remove sites from the GWEN system and transfer the site and equipment to the Department of Transportation. The Army Corps of Engineers will manage the real property of the NDGPS. The Federal Railroad Administration will act as sponsor for the system, and as such, will request funding and personnel. The Federal Highways Administration will complete environmental assessments for the program and sites; design a broadcast site plan; coordinate with states and other federal agencies to acquire sites; and provide coverage verification for each broadcast site. The Coast Guard will furnish technical expertise and support to ensure that the site meet the signal specifications; obtain frequency assignments; procure commercial equipment; acquire commercial installation and maintenance services; provide equipment life cycle support; monitor and control the NDGPS; and coordinate with industry, universities and states to improve the NDGPS to meet the needs of federal, state and local governments as well as the general public. The National Oceanic and Atmospheric Administration will survey the reference stations and lead the integration of the NDGPS into the Integrated Precipitable Water Vapor System.

In addition to the Federal agencies, many states will be involved. Many states have already begun looking for candidate state owned sites for the 26 moved GWENs and 7 new sites that were mentioned earlier. This cooperation from the states will reduce schedule delay risks associated with land acquisition and reduce the cost of implementing the system.

Hopefully, this program will prove that federal and states agencies can work cooperatively with, industry and the international community to accomplish a common goal of providing a seamless navigation system, designed to nonpropriatary standards and free of user fees. The Nationwide DGPS service will guide us into the 2 1 st century using the most accuracy and reliable navigation system the world has ever had. But NDGPS will be more than a navigation system. It will provide: survey grade positioning to users of the CORS network; continuous water vapor information to the national weather models; and a myriad of precision farming applications to American farmers. These multi-billion dollar benefits come at a modest cost of 30 million dollars. This low cost is due to a proven design, use of commercial equipment and services, and the extraordinary cooperation of among federal and state agencies. But beyond the billions of dollars saved, the most important benefit is that NDGPS will save lives -- on the seas, on the roads and on the rails.

If you would like additional information about NDGPS, please contact Leonard Allen at:

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Nationwide Differential Global Positioning System (NDGPS)
Part of
Public Law (105-66)

SEC. 346. (a) As soon as practicable after the date of enactment of this Act, the Secretary of Transportation, acting for the Department of Transportation, may take receipt of such equipment and sites of the Ground Wave Emergency Network (referred to in this section as "GWEN") as the Secretary of Transportation determines to be necessary for the establishment of a nationwide system to be known as the "Nationwide Differential Global Positioning System" (referred to in this section as "NDGPS").

(b) As soon as practicable after the date of enactment of this Act, the Secretary of Transportation may establish the NDGPS. In establishing the NDGPS, the Secretary of Transportation may--

(1) if feasible, reuse GWEN equipment and sites transferred to the Department of Transportation under subsection (a);

(2) to the maximum extent practicable, use contractor services to install the NDGPS;

(3) modify the positioning system operated by the Coast Guard at the time of the establishment of the NDGPS to integrate the reference stations made available pursuant to subsection (a);

(4) in cooperation with the Secretary of Commerce, ensure that the reference stations referred to in paragraph (3) are compatible with, and integrated into, the Continuously Operating Reference Station (commonly referred to as "CORS") system of the National Geodetic Survey of the Department of Commerce; and

(5) in cooperation with the Secretary of Commerce, investigate the use of the NDGPS reference stations for the Global Positioning System Integrated Precipitable Water Vapor System of the National Oceanic and Atmospheric Administration.

(c) The Secretary of Transportation may--

(1) manage and operate the NDGPS;

(2) ensure that the service of the NDGPS is provided without the assessment of any user fee; and

(3) in cooperation with the Secretary of Defense, ensure that the use of the NDGPS is denied to any enemy of the United States.

(d) In any case in which the Secretary of Transportation determines that contracting for the maintenance of 1 or more NDGPS reference stations is cost-effective, the Secretary of Transportation may enter into a contract to provide for that maintenance.

(e) The Secretary of Transportation may--

(1) in cooperation with appropriate representatives of private industries and universities and officials of State governments--

(A) investigate improvements (including potential improvements) to the NDGPS;

(B) develop standards for the NDGPS; and

(C) sponsor the development of new applications for the NDGPS; and

(2) provide for the continual upgrading of the NDGPS to improve performance and address the needs of--

(A) the Federal Government;

(B) State and local governments; and

(C) the general public.